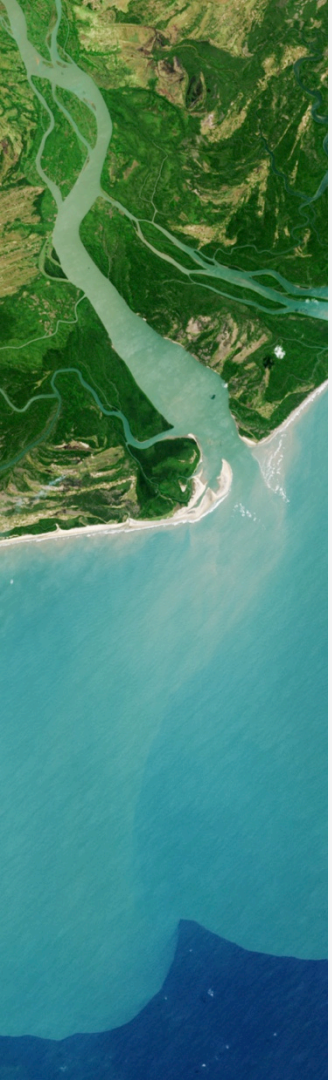


National Aeronautics and Space Administration

ARSET

Applied Remote Sensing Training

http://arset.gsfc.nasa.gov

@NASAARSET

Water Quality Monitoring Using NASA Remote Sensing Observations

Short Course, National Monitoring Conference
May 5, 2016 (8:30 AM – 12 PM)

Instructors:

Amita Mehta (NASA-UMBC-JCET)

Cédric G. Fichot (NASA-JPL)

Objectives

- Provide an overview of NASA remote sensing observations relevant for monitoring water quality (WQ) in coastal oceans, estuaries, and lakes
- Provide training in using web-tools to access the remote sensing imagery and WQ parameters (e.g. Chlorophyll Concentration)
- Provide hands-on experience in access, interpretation, and applications of the remote sensing data for WQ monitoring with the aid of specific case studies

Expected Outcome

- Gain knowledge and ability to access, analyze, and apply satellite remote sensing data for water quality monitoring and management needs
- Learn about advantages and limitations of using remote sensing observations for WQ applications
- There will be an opportunity to provide feedback about the training material and future areas of interest
- More advanced, regionally focused training can be requested that includes downloading and installing/running software to manipulate satellite data to use in WQ applications

Agenda

- Introduction to ARSET (8:30 – 8:40 AM)
- Presentation (8:40 – 9:15 AM)
  - Overview of NASA Remote Sensing Data and Data Access Tools Relevant for Water Quality Monitoring
- Hands-on Exercise of using NASA Web-tools (9:15 – 10:00 AM)
  - Learn to use OceanColor Web and Giovanni: Selection, Visualization, and Downloading water quality (WQ) data
  - Analysis of near-real time and past Chlorophyll-a Concentration in the Great Lakes and Gulf of Mexico
- Break (10:00 – 10:30 AM)
- Demonstration and Follow-along Exercise (10:30 AM – 11:45 AM)
  - Demonstration of GloVIS – learn to access and interpret LANDSAT Imagery
- Course Summary and Question/Answer (11:45 AM – 12 PM)

ARSET
Applied remote Sensing Training program

http://arset.gsfc.nasa.gov

ARSET Training Areas

An Applied Sciences Capacity Building Program

Disasters

Ecological Forecasting

Health & Air Quality

Water Resources

Agriculture

Climate

Energy

Oceans

Meteorology

ARSET Team

Water Resources Team:

- Brock Blevins (UMBC/JCET)
- Amita Mehta (UMBC/JCET)
- Kyle Peterson (UMBC/JCET)
- Cédric Fichot (NASA/JPL)
- Erika Podest (NASA/JPL)
- Tim Stough (NASA/JPL)

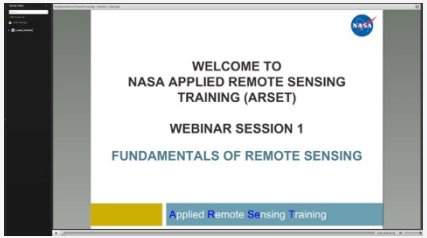
Program Manager:

- Ana Prados (UMBC/JCET)

ARSET

http://arset.gsfc.nasa.gov

Training activities for environmental professionals to increase usage of NASA observational and modeling data for decision-making support.



Online Webinars

- 1 hour a week, 4-6 weeks
- Live & recorded
- Include demos on data access

In-person Workshops

- Held in a computer lab for 2 - 4 days
- Focus on data access
- Locally relevant case studies

Train the Trainers

- Courses & training manuals for those interested in doing their own remote sensing trainings

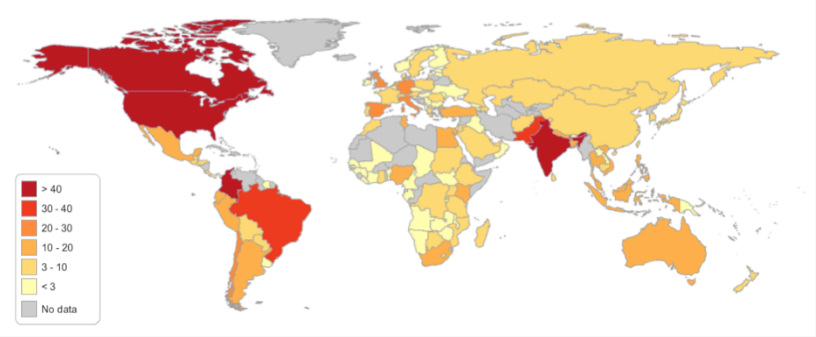
ARSET Trainings

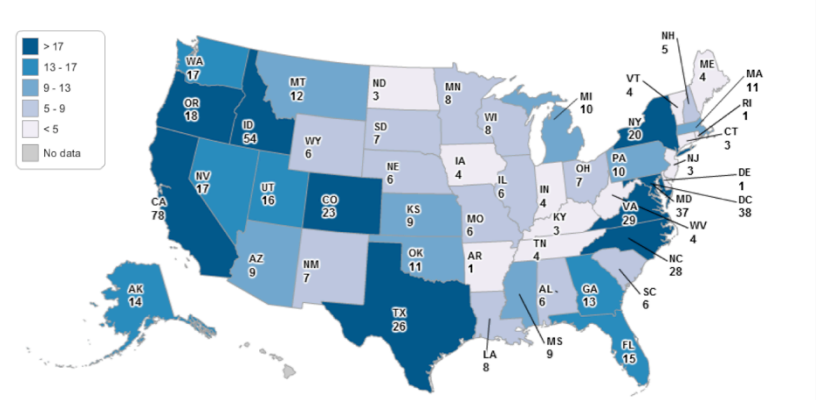
Accomplishments (2008-present)

- 66 Trainings Completed
- 4,000+ participants worldwide from:
  - 1,400+ organizations
  - 130+ countries

“I think the largest benefit to me will be just learning the basics and gaining an understanding of what products and applications are available and how I potentially use these products to help with my responsibilities as a land manager.”
-Participant of a 2015 Wildfire Workshop

Participating Organizations by Country & U.S. States (2008-2015)





ARSET Trainings

Gradual Learning Approach

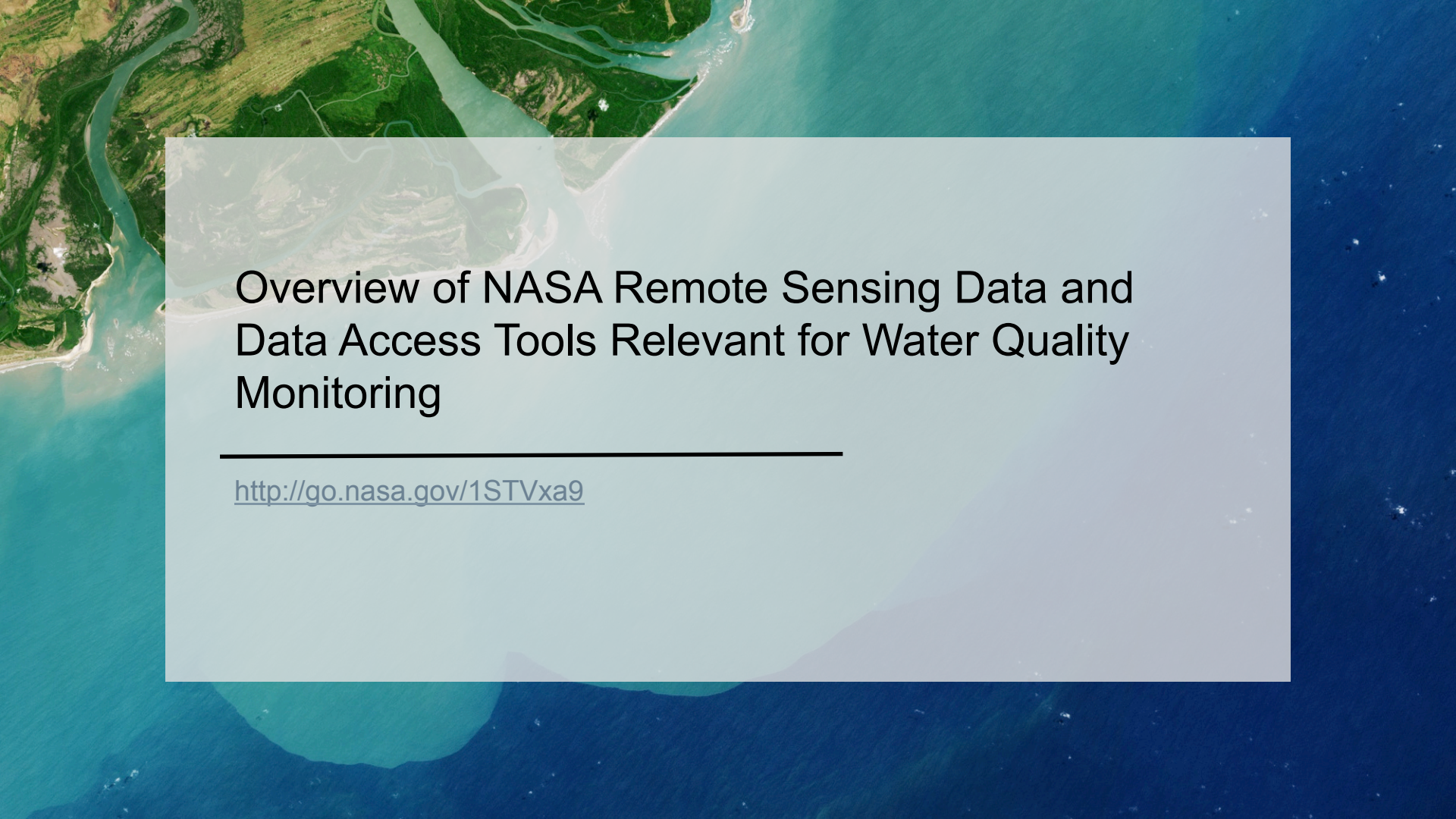
Example: 2014 Webinar
Water Quality Monitoring Using Remote Sensing Measurements
http://go.nasa.gov/1STVxa9

Example:
Algal bloom monitoring in the Great Lakes

ARSET Listserv

For information on upcoming courses and program updates, please sign up to the listserv

https://lists.nasa.gov/mailman/listinfo/arset



Overview of NASA Remote Sensing Data and Data Access Tools Relevant for Water Quality Monitoring

http://go.nasa.gov/1STVxa9

Outline

- Remote Sensing of Water Quality
- Satellites and Sensors Useful for WQ Remote Sensing
- WQ Data and Demonstration of Web-tools to Visualize and Access the Data
- Strengths and Limitations of the Remote Sensing Data for WQ Monitoring
- Examples of NASA Remote Sensing Applications WQ Monitoring

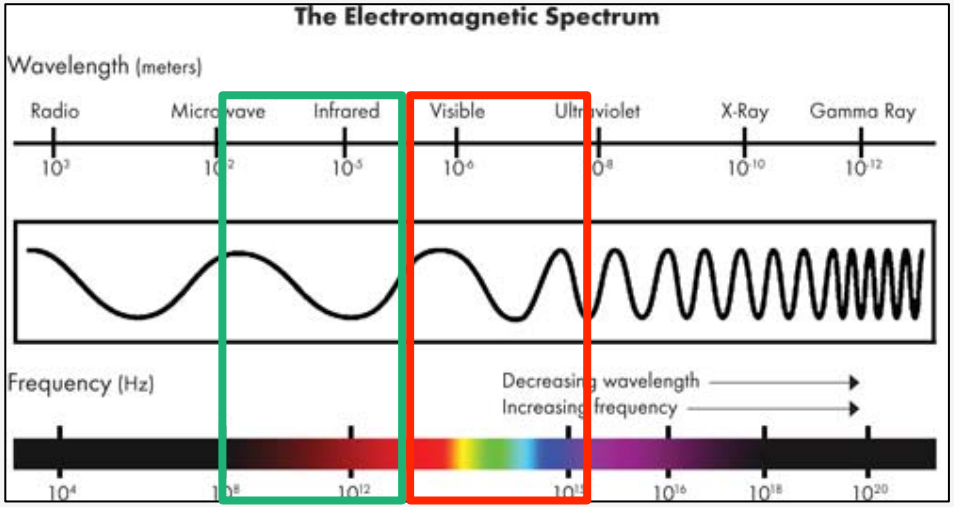
Remote Sensing of Water Quality

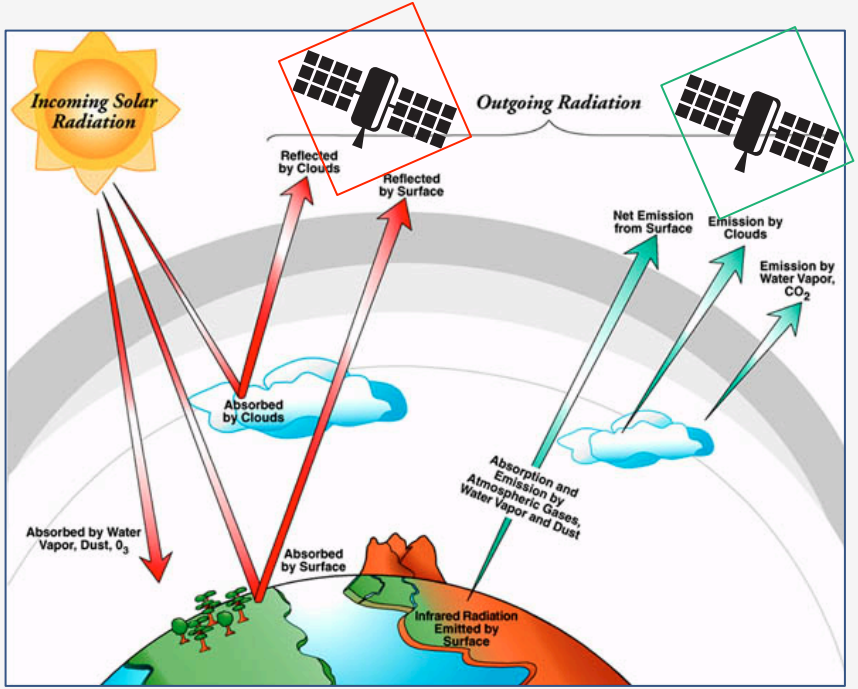
http://arset.gsfc.nasa.gov/webinars/fundamentals-remote-sensing

Satellite Remote Sensing

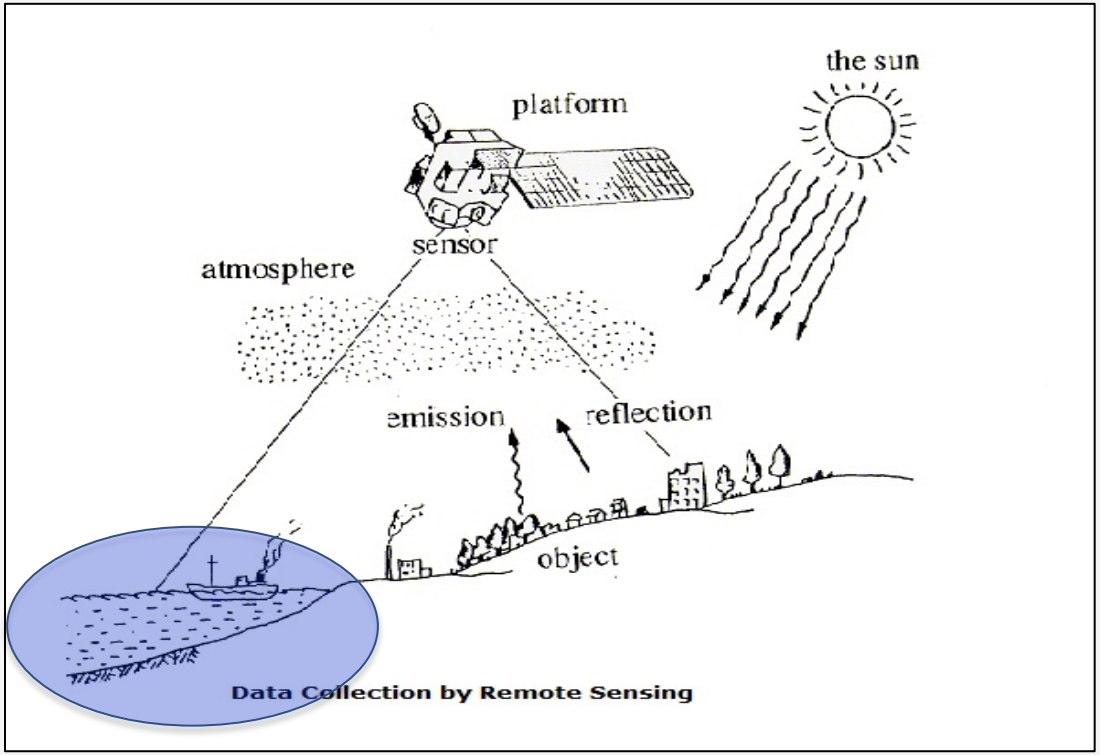
Satellites carry instruments/sensors to measure:

- **reflected solar radiation**
- **emitted infrared and microwave radiation**





Satellite measurements carry information about:



Atmosphere

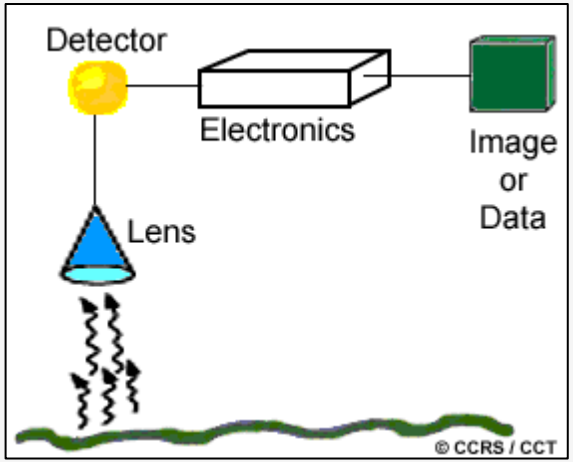
- Clouds
- Aerosols
- Gases

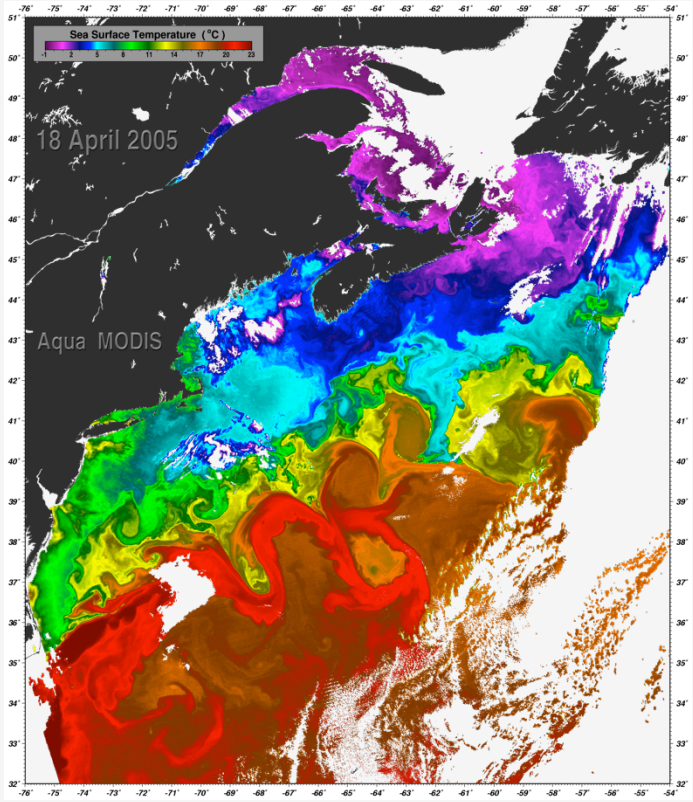
Earth's Surface

- Snow/Ice
- Land
  - Land use
  - Vegetation
- **Water**

Remote Sensing of Water Bodies

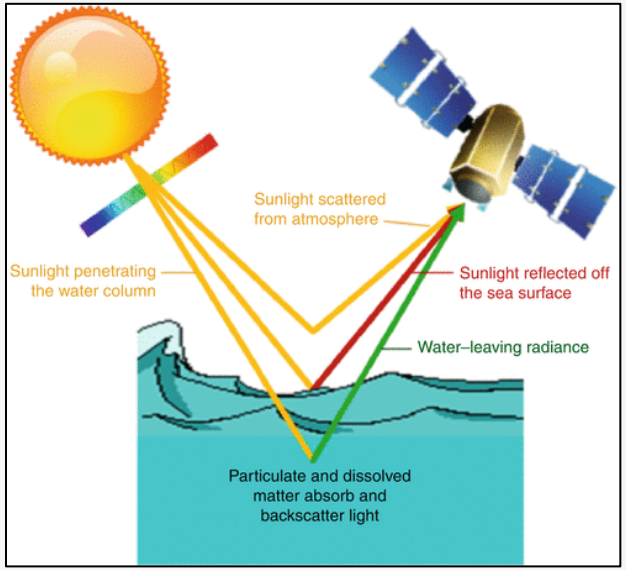
Emitted thermal infrared radiation can be measured by satellite sensors, and used to derive the temperature of surface water bodies.





Remote Sensing of Water Bodies

Reflected solar radiation (~ color of the water) is measured by satellite sensors, and used to derive the properties of optically-active water constituents:



- Suspended sediments
- Algae
- Dissolved Organic Matter
- Detrital Organic Matter
- Submerged/Floating vegetation
- Oil

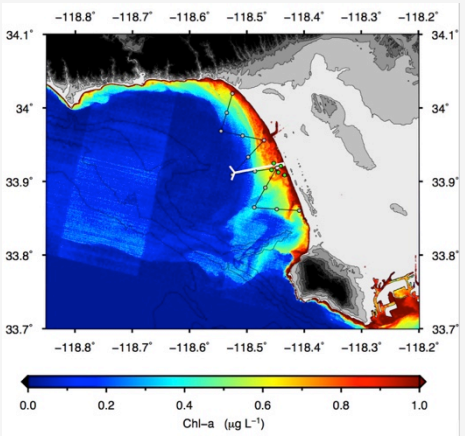
- Contaminants
- Pathogens

Remote Sensing of Water Bodies

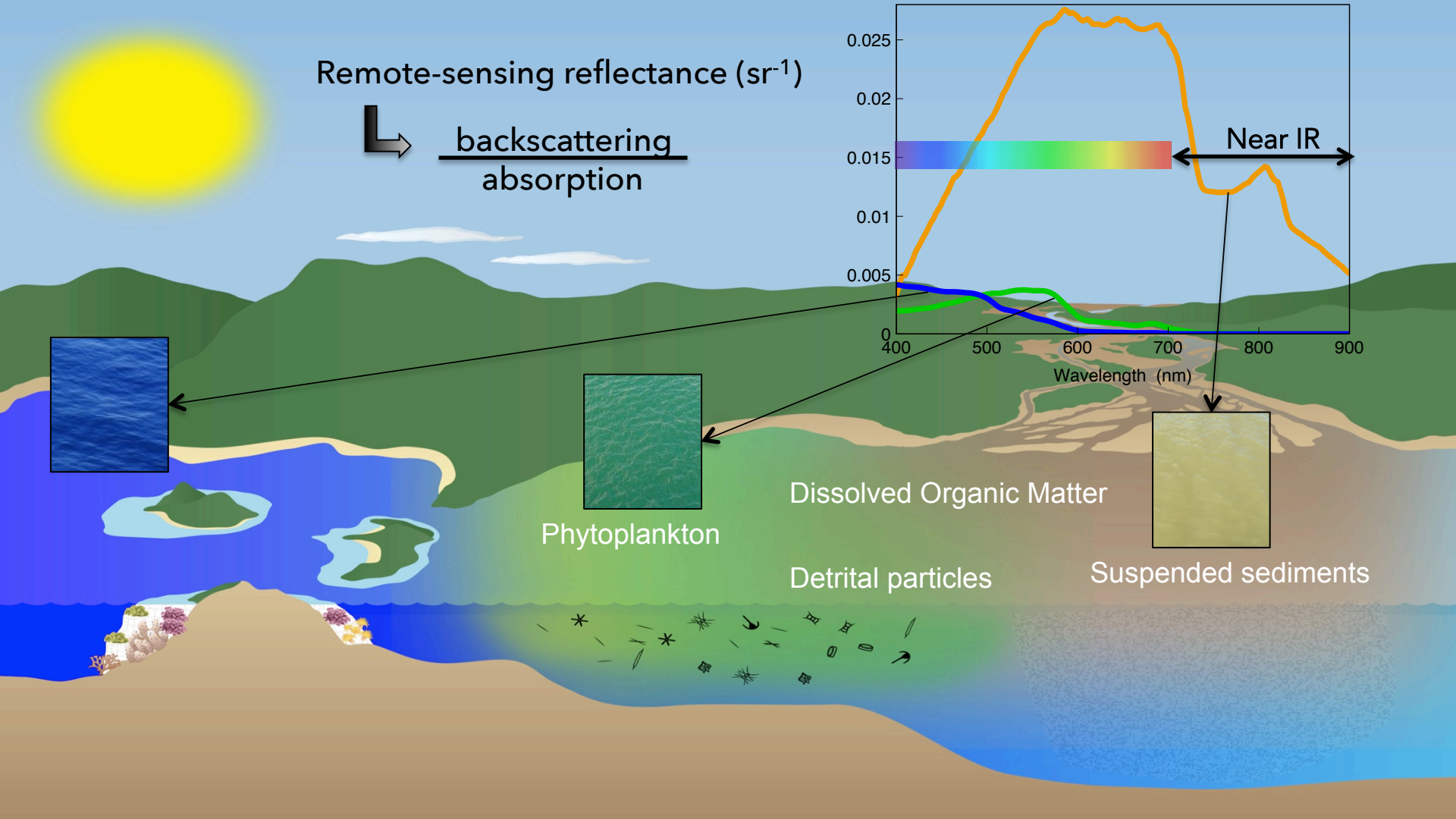
Techniques

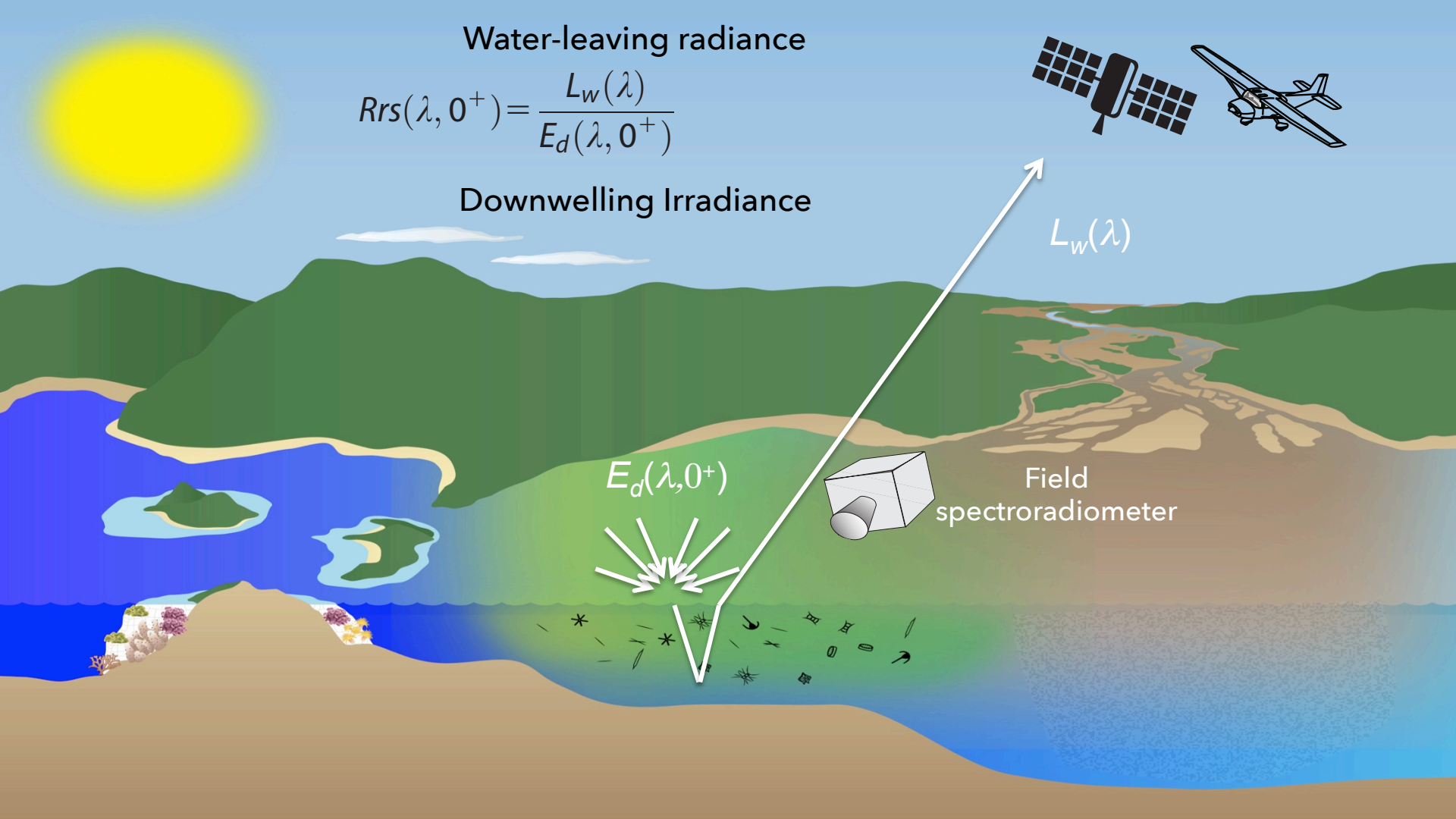
Simple image interpretation to derive *QUALITATIVE information* about water quality

Use of various types of algorithms to derive *QUANTITATIVE information* about water quality



In Situ Observations Required


Remote-sensing reflectance (sr-1)
backscattering
absorption
0.025
0.02
0.015
0.01
0.005
0
400
500
600
700
800
900
Wavelength (nm)
Near IR
Phytoplankton
Dissolved Organic Matter
Detrital particles
Suspended sediments

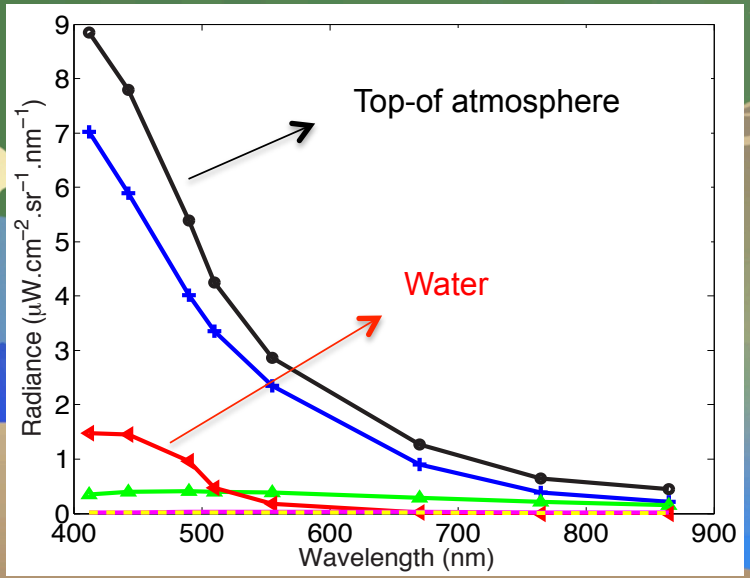

Water-leaving radiance
$Rrs(\lambda, 0^+) = \frac{L_w(\lambda)}{E_d(\lambda, 0^+)}$
Downwelling Irradiance
$L_w(\lambda)$
$E_d(\lambda,0^+)$
Field
spectroradiometer

Atmospheric Correction

$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda,\theta)L_g(\lambda) + t(\lambda,\theta)L_{wc}(\lambda) + t(\lambda,\theta)L_w(\lambda)$$

>90%

<10%

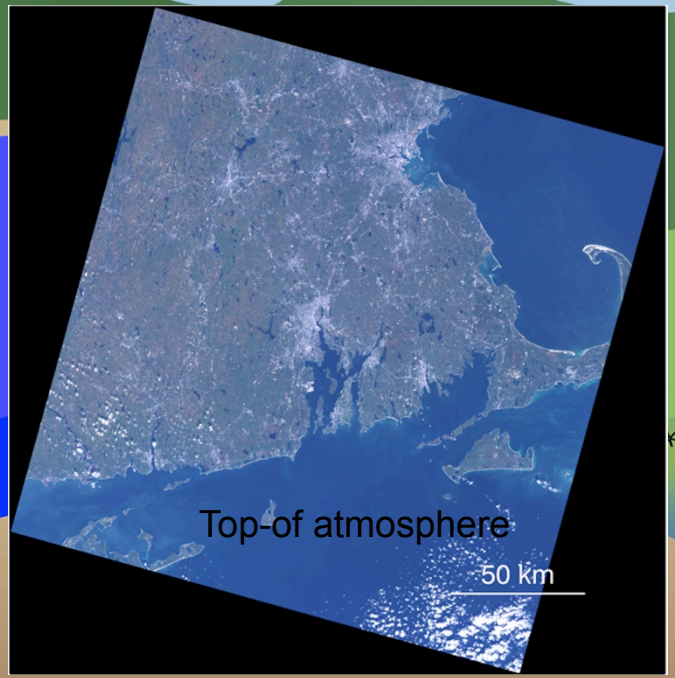


Atmospheric Correction

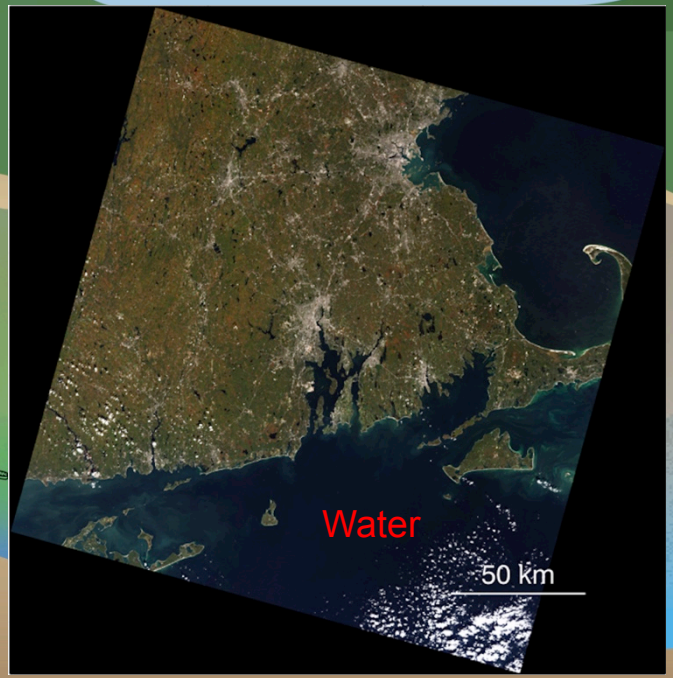
$$L_t(\lambda) = L_r(\lambda) + L_a(\lambda) + L_{ra}(\lambda) + T(\lambda,\theta)L_g(\lambda) + t(\lambda,\theta)L_{wc}(\lambda) + t(\lambda,\theta)L_w(\lambda)$$

>90%

<10%



Atmospheric correction



Satellites and Sensors for Water Quality

Overview of NASA Satellites & Sensors for Water Quality Monitoring

- Currently several satellites observe water surface properties in:
  - Coastal oceans and estuaries
  - Many in-land lakes

- A number of WQ parameters are operationally available from these satellites
  - Temperature
  - Chl-a

Overview of NASA Satellites & Sensors for Water Quality Monitoring

Satellite	Sensor	Parameter
Landsat Series (7/1972 - present)	• Thematic Mapper (TM) • Enhanced Thematic Mapper (ETM+) • Operational Land Imager (OLI)	• Spectral Reflectance
Terra (12/1990-present)	Moderate Resolution Imaging Spectroradiometer (MODIS)	• Spectral Reflectance • Chlorophyll-a Concentration • Temperature • Colored Dissolved Organic Matter (CDOM) • Turbidity • Euphotic Depth
Aqua (5/2002-present)		
Terra (12/1999 – present)	Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)	• Spectral Reflectance • Temperature
National Polar Partnership (NPP) (11/2011-present)	Visible Infrared Imaging Radiometer Suite (VIIRS)	• Spectral Reflectance • Chlorophyll Concentration

Landsat Satellites and Sensors

http://landsat.gsfc.nasa.gov

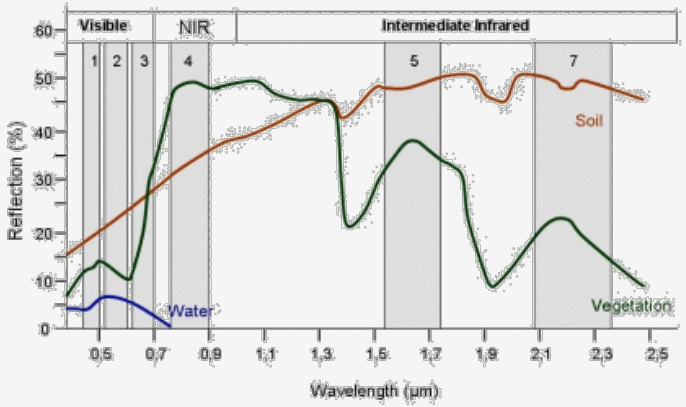
http://landsat.usgs.gov//about_mission_history.php

- Near-polar orbit, 10 a.m. equator-crossing time
- Global coverage
- July 1972 – Present
  - 16 day revisit time
- Sensors
  - MSS
  - TM
  - ETM+
  - OLI
  - TIRS

Enhanced Thematic Mapper (ETM+)

http://geo.arc.nasa.gov/sge/landsat/l7.html

- Flying on-board Landsat-y polar orbiting satellites
- Spatial Coverage and Resolution:
  - Global, swatch: 185km
  - Spatial resolution: 15m, 30m, 60m
- Temporal Coverage and Resolution
  - April 15, 1999 – present
  - 16 day revisit time

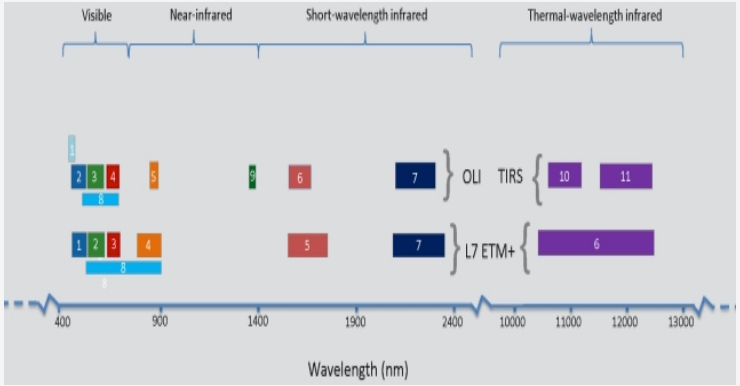


- **Spectral Bands: 8**
  - Major bands include: blue-green, green, red, reflected and thermal IR, panchromatic
- Bands 1-5 & 7: 30m
- Band 6: 60m
- Band 8: 15m

Operational Land Imager (OLI)

http://landsat.usgs.gov/landsat8.php and http://landsat.gsfc.nasa.gov/?p=5779

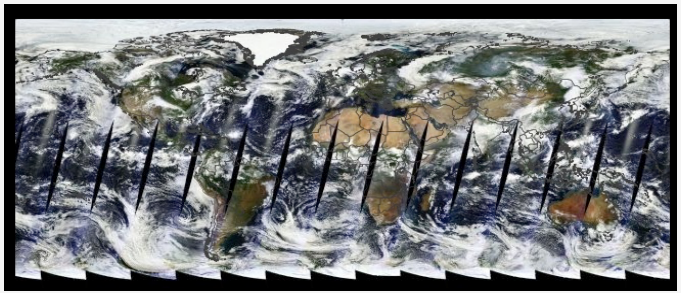
- Flying on-board Landsat-8 polar orbiting satellite
  - Landsat Data Continuity Mission (LDCM)
- Spatial Coverage and Resolution
  - Global, swath 185km
  - Spatial resolution: 15km, 30m
- Temporal Coverage and Resolution
  - February 11, 2013 – present
  - 16 day revisit time



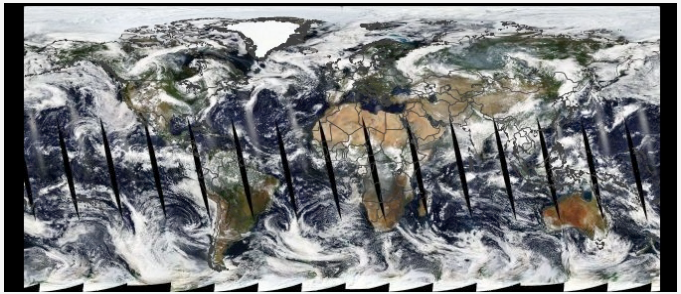
- **Spectral Bands: 9**
  - Major bands include blue-green, red, near IR, shortwave and thermal IR, panchromatic
- Bands 1-7 & 9: 30m
- Band 8: 15m

Terra and Aqua

http://terra.nasa.gov



http://aqua.nasa.gov/



Terra:

- Polar orbit, 10:30 am equator crossing time
- Global Coverage
- December 18,1999 – Present
- 1-2 observations per day

Sensors:
ASTER, CERES, MISR, MODIS, MOPITT

Aqua:

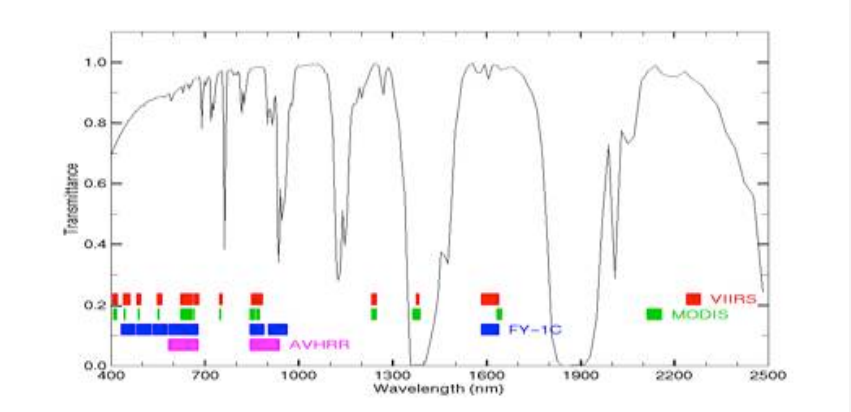
- Polar orbit, 1:30 pm equator crossing time
- Global Coverage
- May 4, 2002 – Present
- 1-2 observations per day

Sensors:
AIRS, AMSU, CERES, MODIS, AMSR-E

MODerate Resolution Imaging Spectroradiometer (MODIS)

http://modis.gsfc.nasa.gov

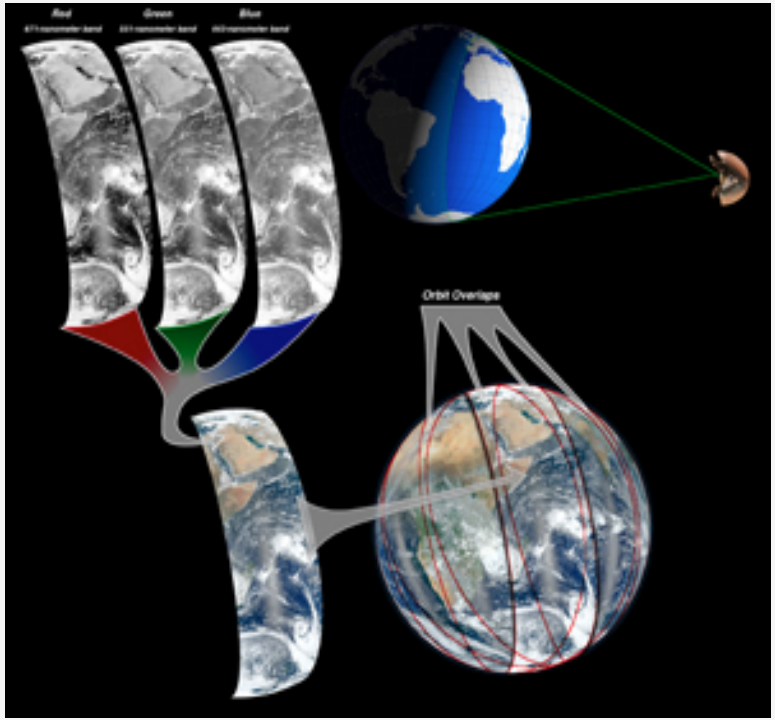
- Flying on-board Terra & Aqua polar orbiting satellites
  - Designed for land, atmosphere, ocean and cryosphere observations
- Spatial Coverage and Resolution
  - Global, swath width: 2330 km
  - Spatial resolution varies: 250m, 500m, 1km
- Temporal Coverage and Resolution
  - 2000-present, 2 times per day



- **Spectral Bands: 36**
  - Major bands includes red, blue, IR, NIR, MIR
- Bands 1-2: 250m
- Bands 3-7: 500m
- Bands 8-36: 1000m

National Polar Partnership (NPP)

http://www.nasa.gov/mission_pages/NPP

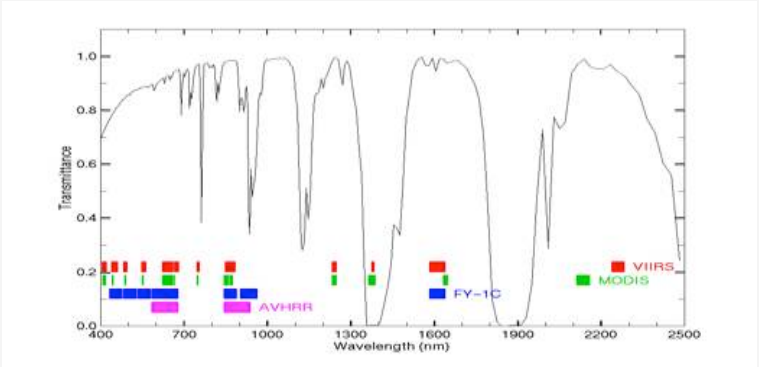


- Polar Orbit, 1:30 p.m. equator crossing time
- Global coverage
- November 21, 2011- present
  - 1-2 observations per day
- Sensors
  - VIIRS
  - ATMS
  - CrIS
  - OMPS
  - CERES

Visible Infrared Imaging Radiometer Suite (VIIRS)

http://npp.gsfc.nasa.gov/viirs.html

- Flying on-board NPP – polar orbiting satellite
  - Designed to collect measurements of clouds, aerosols, ocean color, surface temperature, fires, and albedo
- Spatial Coverage and Resolution
  - Global, swatch width: 3040km
  - Spatial resolution: 375m to 750m
- Temporal Coverage and Resolution
  - October 2011-present
  - 2 times per day



- **Spectral Bands: 15**
  - Major bands include visible, red, blue, green, short, middle, and long-wave IR
- Ocean color bands 1-7
  - 0.402 – 0.682 μm
- Sea surface temperature bands 12-13
  - 3.660 – 4.128 μm

WQ Data and Demonstration of Web Tools - Giovanni and OceanColor Web Visualize and Access the Data

Water Quality Data

Satellite	Sensor	Parameter
Landsat Series (7/1972 - present)	• Thematic Mapper (TM) • Enhanced Thematic Mapper (ETM+) • Operational Land Imager (OLI)	• **Spectral Reflectance**
Terra (12/1990-present)	Moderate Resolution Imaging Spectroradiometer (MODIS)	• **Spectral Reflectance** • **Chlorophyll-a Concentration** • **Temperature** • **Colored Dissolved Organic Matter (CDOM) Index** • **Turbidity** • **Euphotic Depth**
Aqua (5/2002-present)		
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National Polar Partnership (NPP) (11/2011-present)	Visible Infrared Imaging Radiometer Suite (VIIRS)	• **Spectral Reflectance** • **Chlorophyll Concentration**

Levels of Data

Level 0 Raw Instrument Data

Level 1 Geolocated and Calibrated

Level 2 Geophysical Data Product Derived from L1 Data

Level 3 Composites of Level 2 Data Products

Level 4 Model-derived Data Product

- **Orbital Data (Levels 0, 1, 2)**
  - More user control
  - Highest spatial/temporal resolution
  - Harder to use
- **Gridded Data Products (Levels 3, 4)**
  - Less user control
  - Lower spatial/temporal resolution but gridded and may be available at multiple spatial/temporal resolutions
  - More web tools available for analysis/ access
  - Easier to use

Water Quality Access Tools

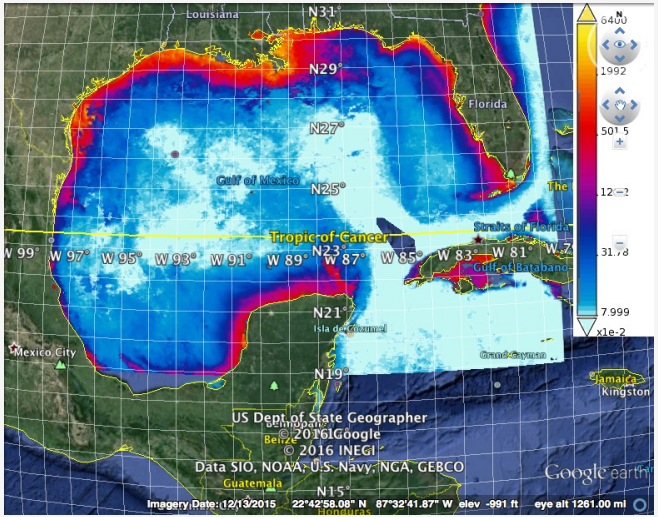
Satellite/Sensor	Data Access Tool	Source	Coverage	Spatial Resolution
Terra and Aqua: MODIS WQ Parameters	**Giovanni** **Seadas/Oceancolor Web**	NASA Goddard Earth Sciences, Data &Information Services Center	8-day and monthly Composites 2000-present	9 km and 4 km
MODIS : Level 1 & 2 Data Level 3 Data	**OceanColor Web**	NASA	Daily Daily, 3 and 8 day Composites, Monthly, Seasonal 2000-present	250 m 9 km and 4 km
Landsat* Tm, ETM+ EO-1/Hyperion Terra/ASTER Spectral Reflectance	LandsatLook Viewer* **GloVIS** EarthEXploer	USGS	July 1972-presnet	30 -60 m (Landsat and EO1-) 15 m (ASTER)
NPP/VIIRS WQ Parameters	STAR	NOAA	October 2011-present	375 m

Giovanni

http://giovanni.gsfc.nasa.gov/giovanni

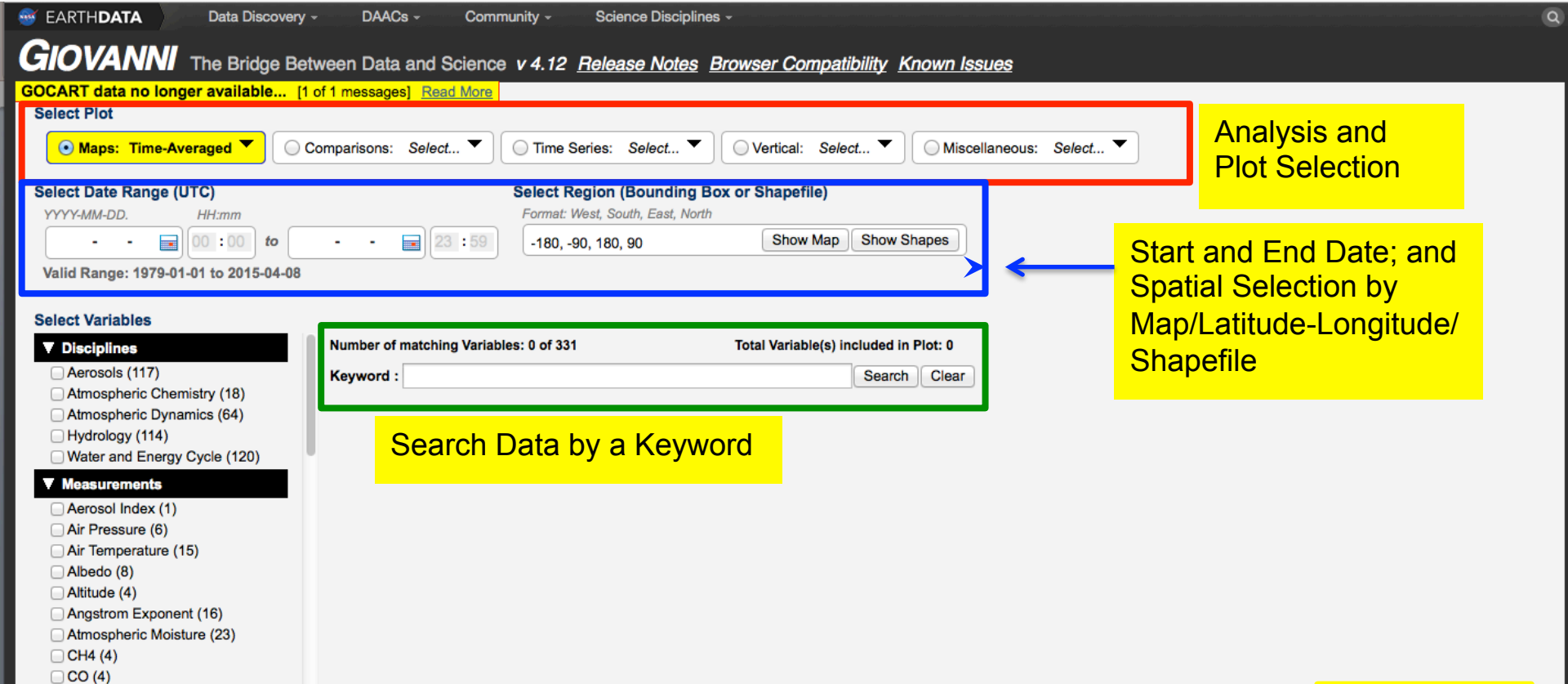
- Giovanni:
  - **G**eospatial **I**nteractive **O**nline **V**isualization **AN**d a**N**alysis **I**nfrastructure
- A web-based application developed by the Goddard Earth Sciences Data & Information Services Center (GES DISC)
- Provides a simple and intuitive way to visualize, analyze, and access vast amounts of Earth science remote sensing data without having to download the data

- **Available Data:**
  - MODIS-Aqua Chlorophyll Concentration Monthly, 4km (7/2002 – 2/2016)



Giovanni – User Selections

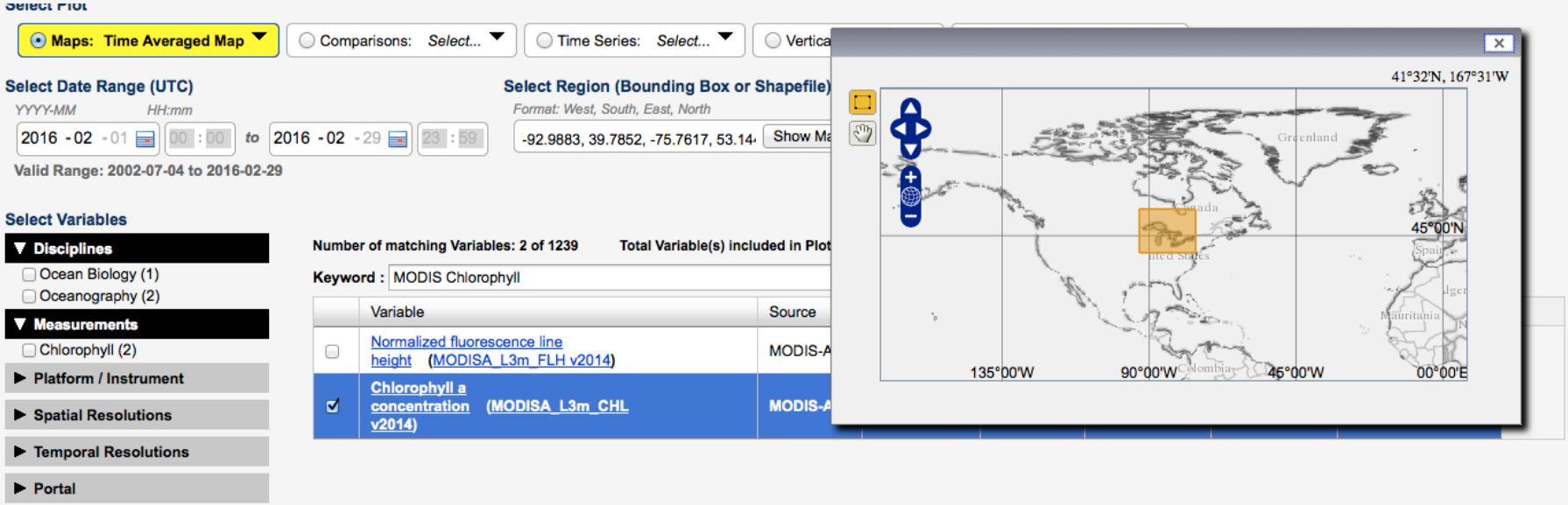
http://giovanni.gsfc.nasa.gov/giovanni



Giovanni – User Selections

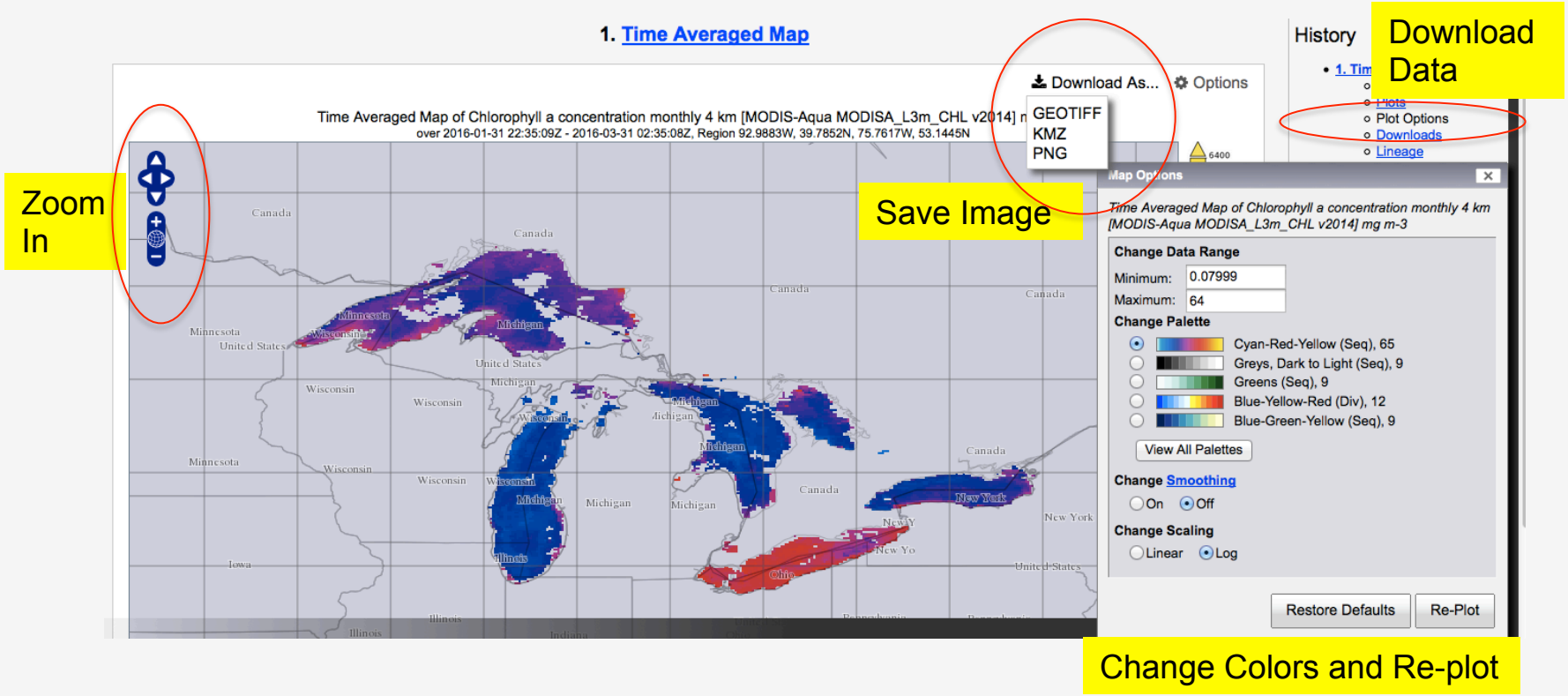
http://giovanni.gsfc.nasa.gov/giovanni

MODIS-based Chlorophyll Concentration for February 2016 in the Great Lakes



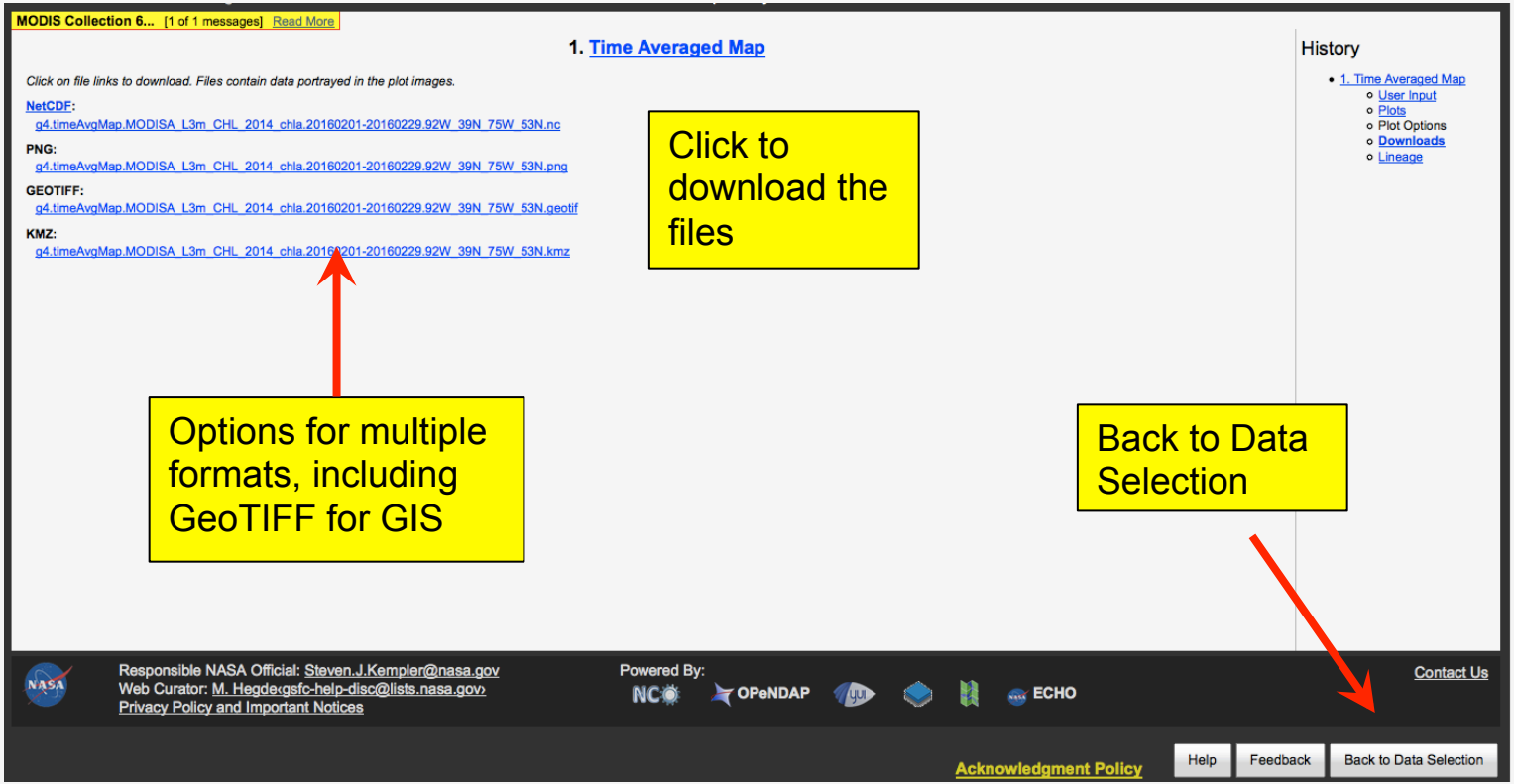
Giovanni – Visualization

http://giovanni.gsfc.nasa.gov/giovanni



Giovanni – Data Download

http://giovanni.gsfc.nasa.gov/giovanni



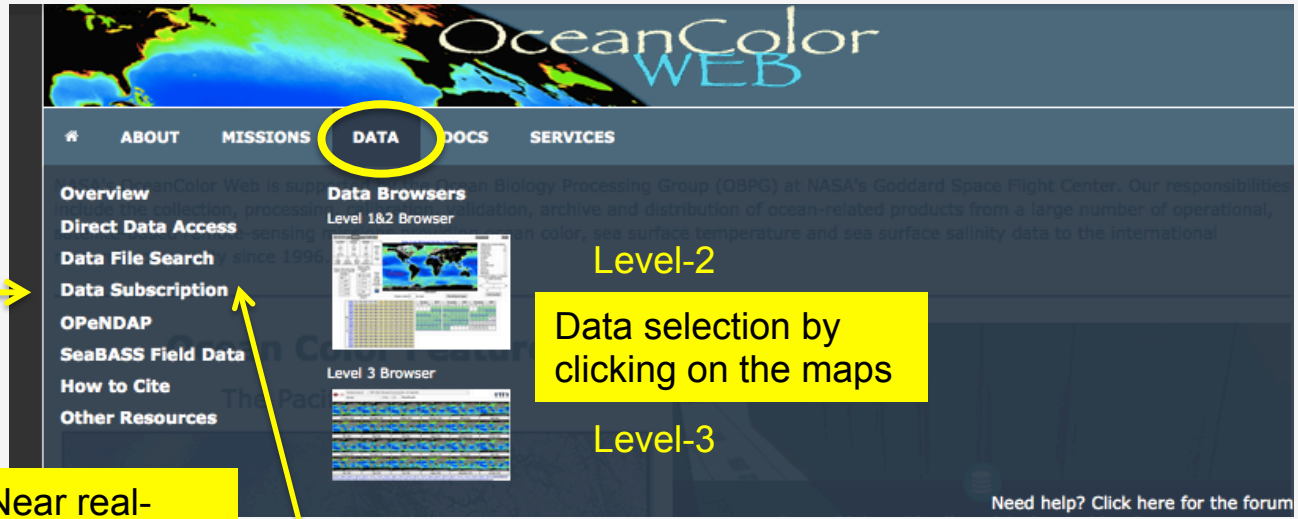
OceanColor Web

http://oceancolor.gsfc.nasa.gov/cms

- Developed for collection, processing, validation, and distribution of ocean-related products from remote sensing and in situ observations
- Useful for monitoring costal and in-land water bodies and estuaries
- Provides visual data browsing capability for L1/L2 and L3 data [Chlorophyll Concentration- Chl, Sea Surface Temperature- SST] from selected sensors, and advance capability of processing remote sensing images by using SeaDAS

OceanColor Web - Data Visualization and Data Access

http://oceancolor.gsfc.nasa.gov/cms



Level-2

Data selection by clicking on the maps

Level-3

Near real-time data can be subscribed

Data search and download

Available Missions

Ancillary
Aquarius *
CZCS*
HICO *
MERIS *
MODIS-Aqua
MODIS-Terra
OCTS*
SeaWiFS*
VIIRS

* Past Missions

OceanColor Web: L1 Images and L2 Data Visualization

http://oceancolor.gsfc.nasa.gov/cms

Parameter Selection

Zoom on a Region

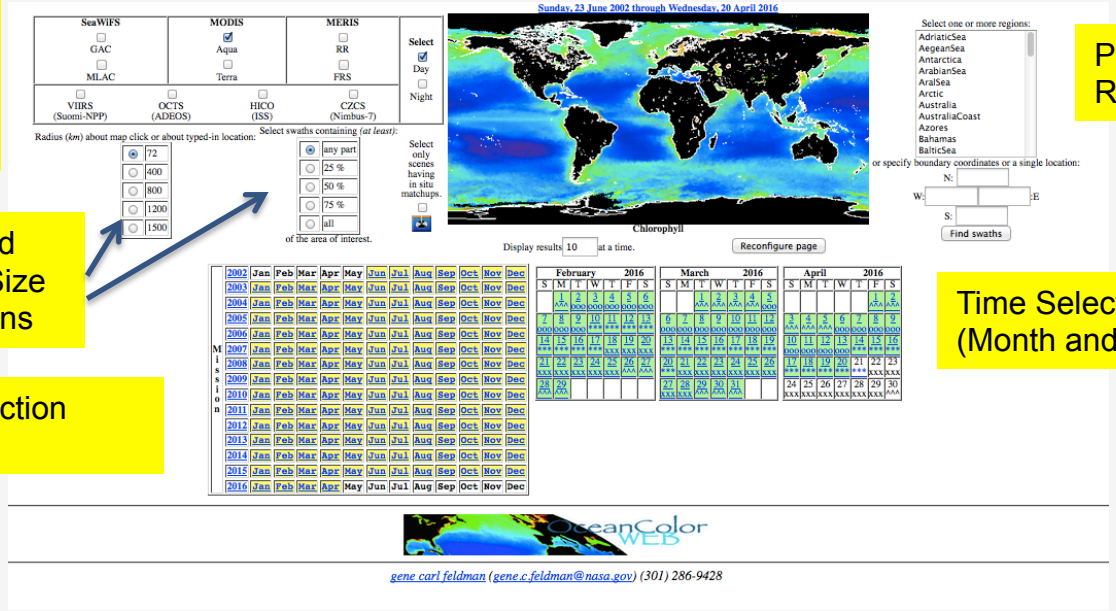
MODIS and VIIRS Near Real-Time and Past Chlorophyll Data

Pre-defined Regions

Area and Swath Size Selections

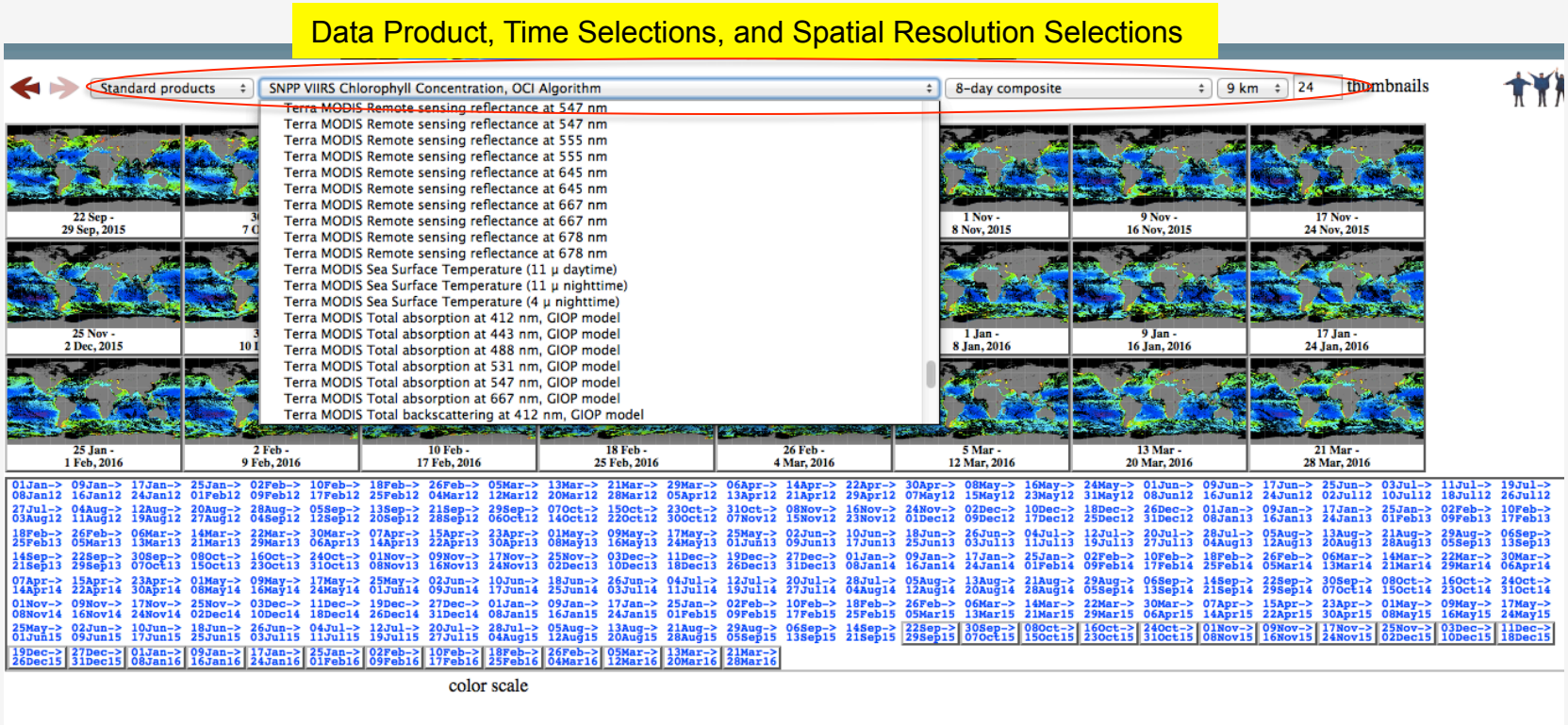
Time Selection (Year)

Time Selection (Month and Day)



OceanColor Web: L3 Data Visualization

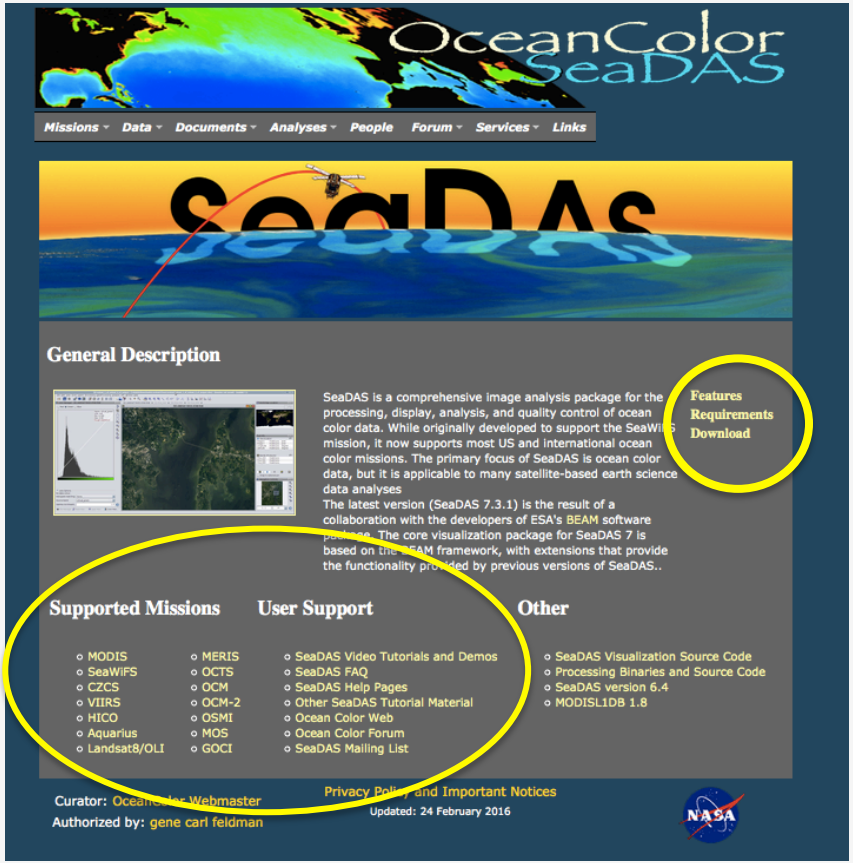
http://oceancolor.gsfc.nasa.gov/cms



SeaDAS: Data Analysis Package

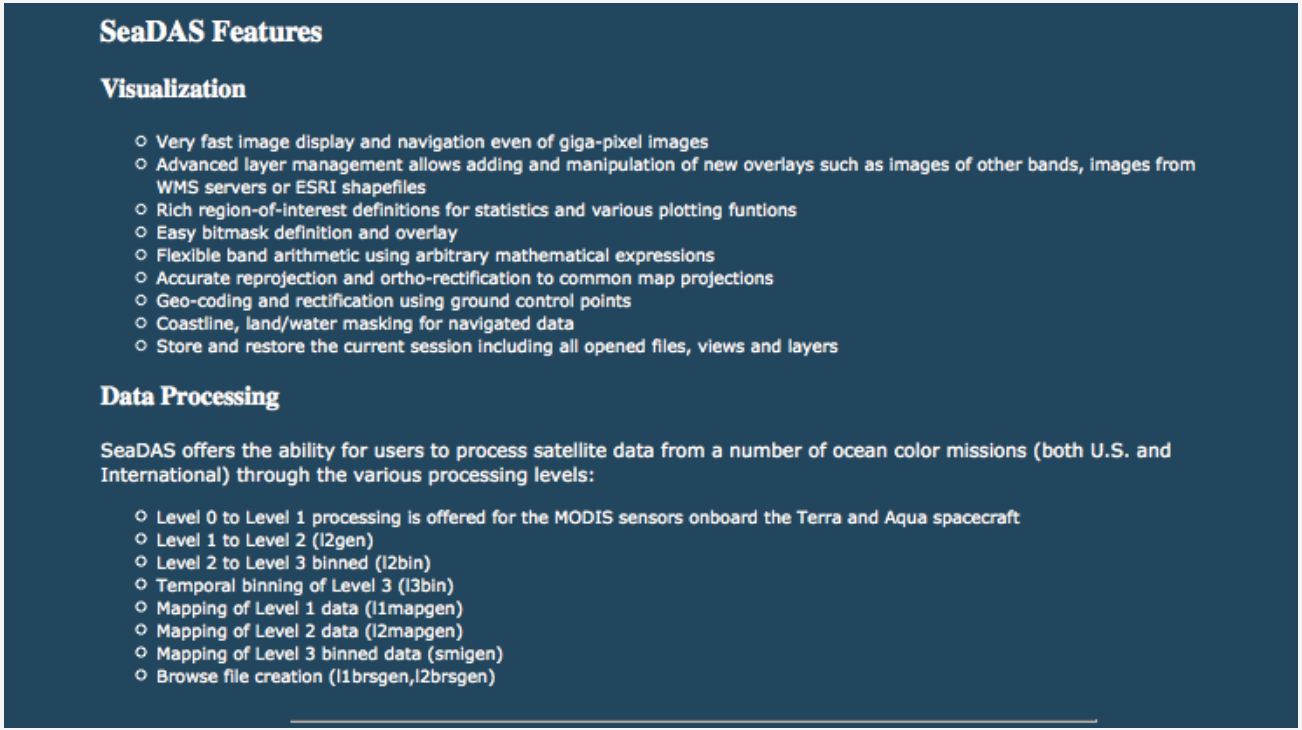
http://seadas.gsfc.nasa.gov/

- SeaDAS is a comprehensive image analysis package developed for the processing, display, analysis, and quality control of ocean color data.
- The latest version (SeaDAS 7.3.1) is developed in a collaboration with the developers of ESA's BEAM software package.



SeaDAS: Features

http://seadas.gsfc.nasa.gov/



SeaDAS Features

Visualization

- Very fast image display and navigation even of giga-pixel images
- Advanced layer management allows adding and manipulation of new overlays such as images of other bands, images from WMS servers or ESRI shapefiles
- Rich region-of-interest definitions for statistics and various plotting funtions
- Easy bitmask definition and overlay
- Flexible band arithmetic using arbitrary mathematical expressions
- Accurate reprojection and ortho-rectification to common map projections
- Geo-coding and rectification using ground control points
- Coastline, land/water masking for navigated data
- Store and restore the current session including all opened files, views and layers

Data Processing

SeaDAS offers the ability for users to process satellite data from a number of ocean color missions (both U.S. and International) through the various processing levels:

- Level 0 to Level 1 processing is offered for the MODIS sensors onboard the Terra and Aqua spacecraft
- Level 1 to Level 2 (l2gen)
- Level 2 to Level 3 binned (l2bin)
- Temporal binning of Level 3 (l3bin)
- Mapping of Level 1 data (l1mapgen)
- Mapping of Level 2 data (l2mapgen)
- Mapping of Level 3 binned data (smigen)
- Browse file creation (l1brsgen,l2brsgen)

SeaDAS: System Requirement

http://seadas.gsfc.nasa.gov/

- Visualization-only version
- Visualization and data processing version
- Multiple mission data can be analyzed
- SeaDAS download, installation, and usage require advance training

SeaDAS Configuration and Requirements

SeaDAS is currently available for Linux, Mac OS X, and Windows. The Windows version currently does not support the science data processing code. The SeaDAS source code is publicly available.

Suggested Hardware Requirements:

Platforms:	Linux Intel Mac OS X
Memory:	256MB minimum, 1GB+ suggested
Disk:	SeaDAS software package (display only version): ~200MB SeaDAS software package (with processing capabilities for all sensors): ~5GB 10GB of free space is also suggested for rudimentary data processing and storage.
Display:	15" Console or X-terminal with 20MB memory 1280x1024 resolution 24-bit X display plane depth 256 colors display minimum

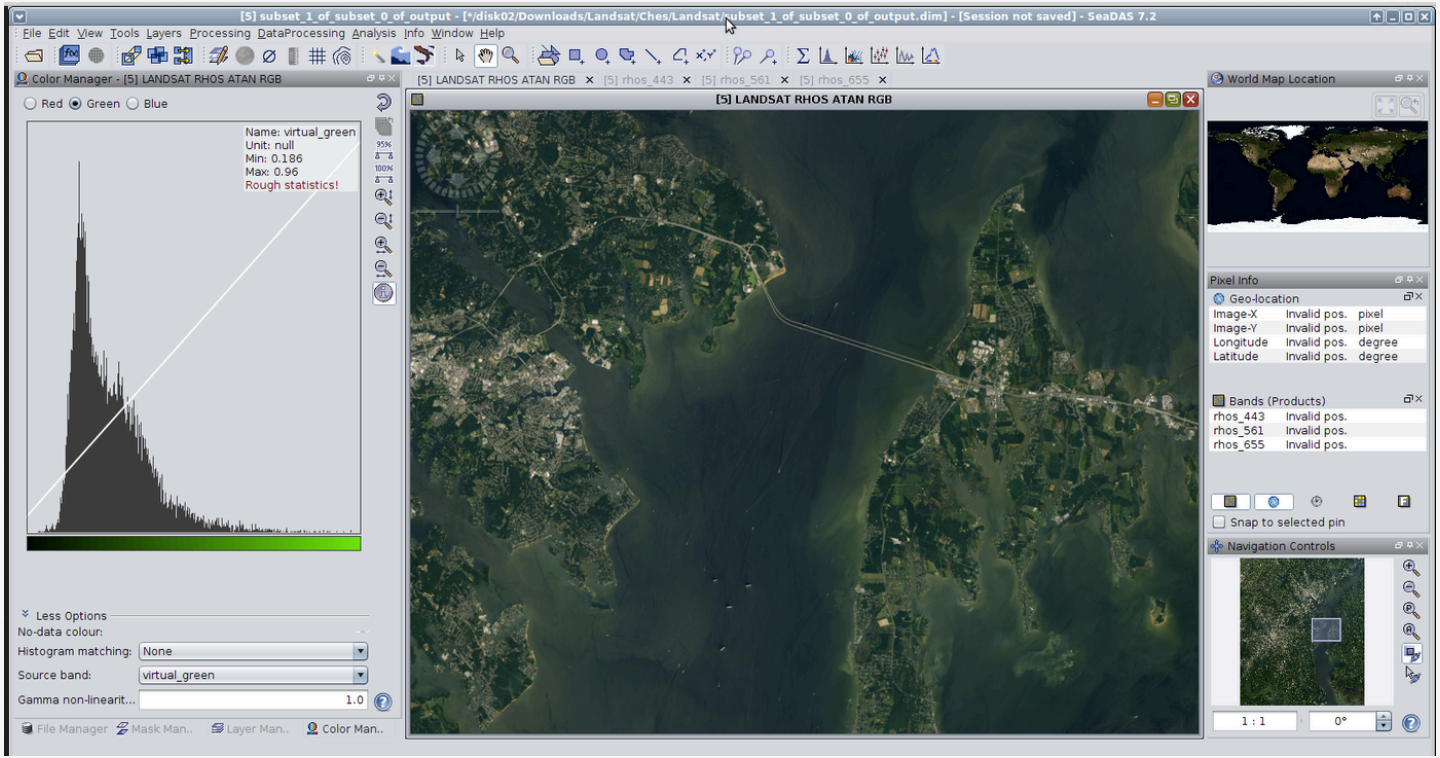
Requirements:
The core visualization package of SeaDAS is written in Java. A minimum Java JRE of version 1.7 is required. A suitable JRE is packaged with the Windows and MacOSX distributions. Linux users will need to separately install a suitable JRE.

Operating Systems:	**Linux:** tested on various versions of CentOS, Fedora, and Ubuntu **Intel Mac:** OS X 10.10
Optional Compilers:	gcc/g++/gfortran (version 4.5 or higher) or Intel Compilers

Program	***Version***	***Notes***
Java	JRE 1.7 or above	Windows and MacOSX distributions come with a suitable JRE Linux users will need to separately install a suitable JRE
Bash	4.x	version 3.x should work, but not tested necessary only for science code, thus not required for Windows distributions
Python	2.6.5 or above	necessary only for science code, thus not required for Windows distributions; not (yet) compatible with version 3 and above
Git	1.7.9 or above	necessary only for science code install/update option, thus not required for Windows distributions
cURL	7.x or above	necessary only for science code install/update option, thus not required for Windows distributions

SeaDAS: Example

http://seadas.gsfc.nasa.gov/



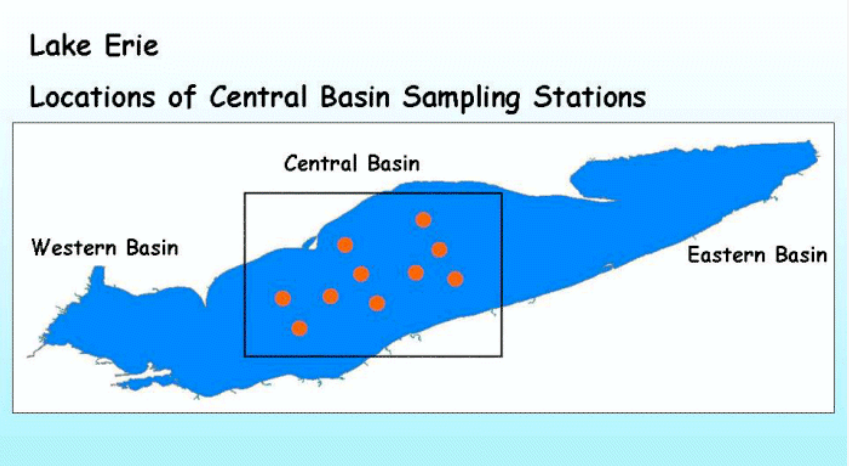
Strengths and Limitations of the Remote Sensing Data for WQ Monitoring

Remote Sensing Observations: Trade Offs

- It is difficult to obtain extremely high spectral, spatial, temporal and radiometric resolution at the same time
- Several sensors can obtain global coverage every one to two days because of their wide swath width (for example, MODIS on Terra/Aqua) but have spatial resolution of 250 m to 1 km
- Higher spatial resolution (30 m) polar orbiting satellites (for example, Landsat)have lower temporal resolution of 16 days
- Large amount of data with varying formats
- Data applications may require additional *in situ* measurements, processing, visualization and other tools

Limitations of In Situ Observations for Water Quality Monitoring

- In situ measurements have limited sample collection – not representative of entire water body
- Periodic sample collection may not capture daily, monthly, or seasonal water quality changes
- Labor intensive and expensive

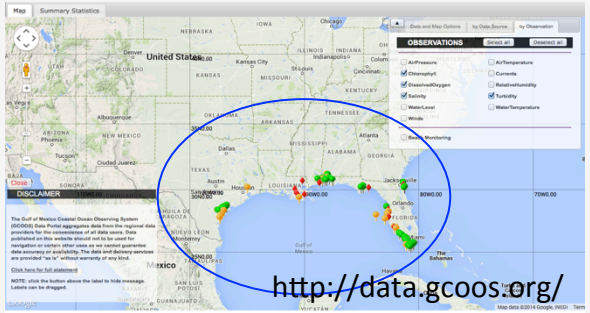


http://epa.gov/greatlakes/monitoring/

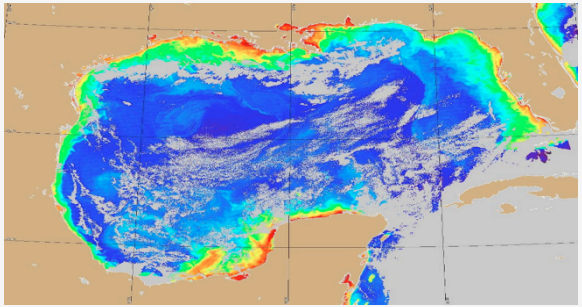
Advantage of Remote Sensing Observations for Water Quality Monitoring

- Provides information where there are no surface-based measurements available and augments when available
- Provides global/near-global coverage with consistent observations
- Provides continuous coverage in comparison to point measurements

Limited Water Sampling Locations

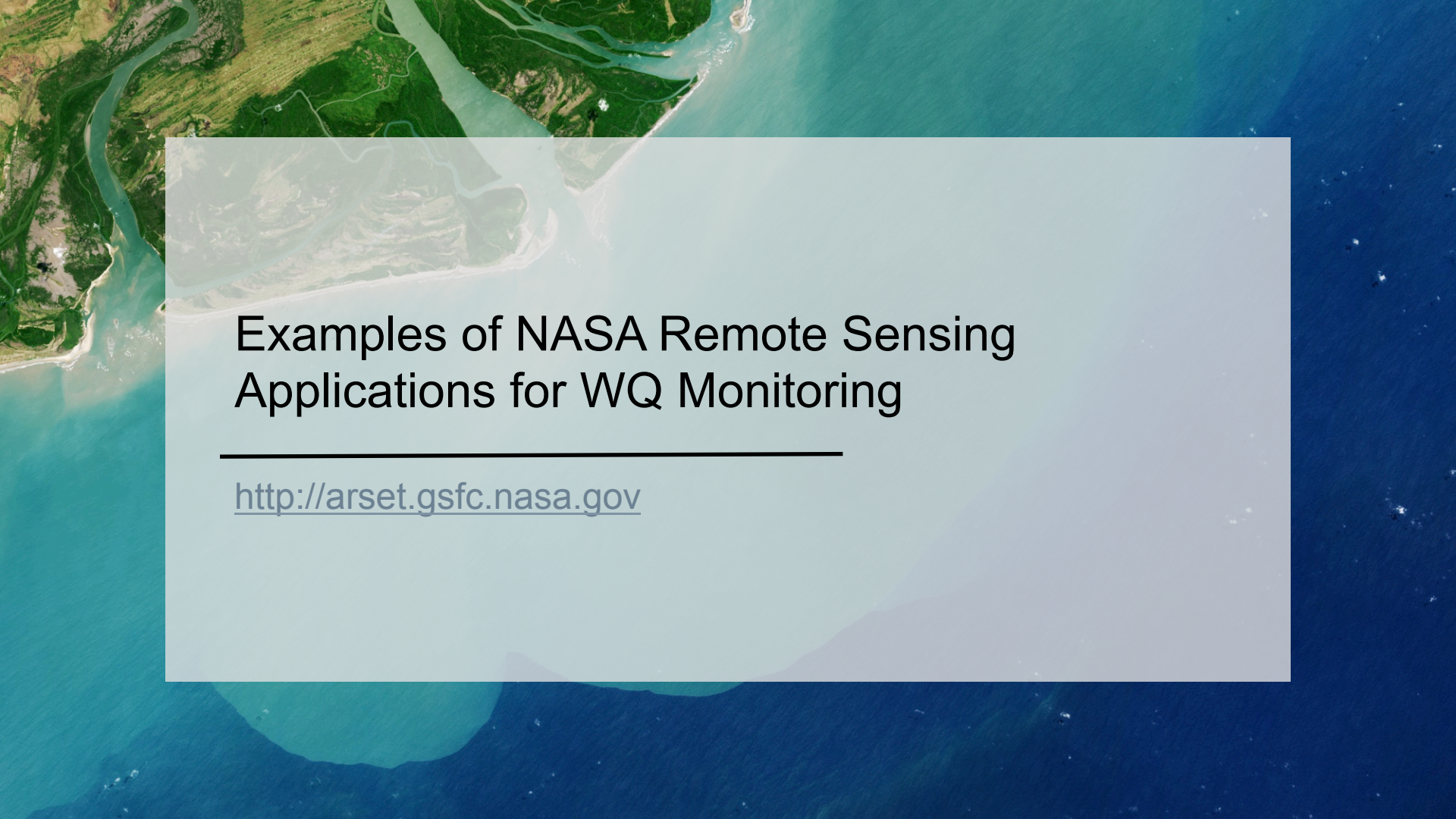


MODIS Aqua satellite image from October 23, 2011, showing areas of elevated chlorophyll a (in red and orange)



Limitations of Remote Sensing Observations for Water Quality Monitoring

- Spectral reflectance in the presence of clouds may be unsuitable for monitoring WQ
- Atmospheric contribution to the reflectance has to be corrected to get the surface water properties
- Medium-spectral bands data may contain effect of multiple WQ parameters
- In the coastal zones data may contain land contribution

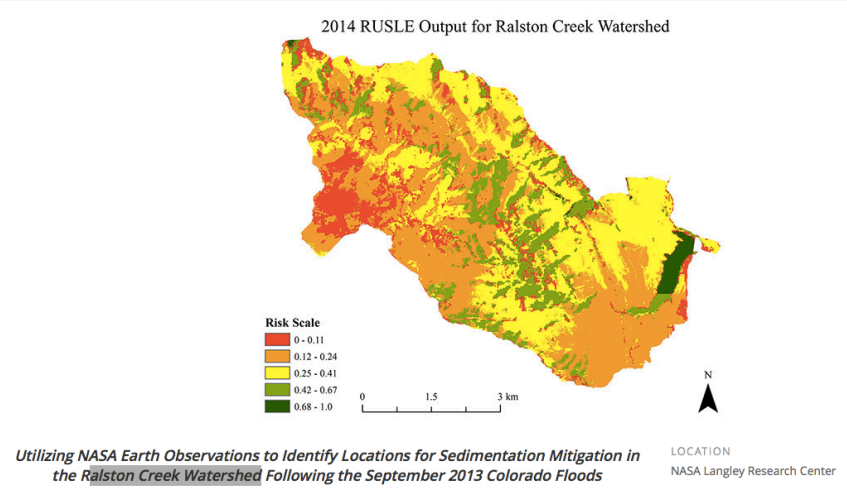


Examples of NASA Remote Sensing Applications for WQ Monitoring

http://arset.gsfc.nasa.gov

Sedimentation Mitigation in a Colorado Watershed

NASA DEVELOP Project - http://develop.larc.nasa.gov/



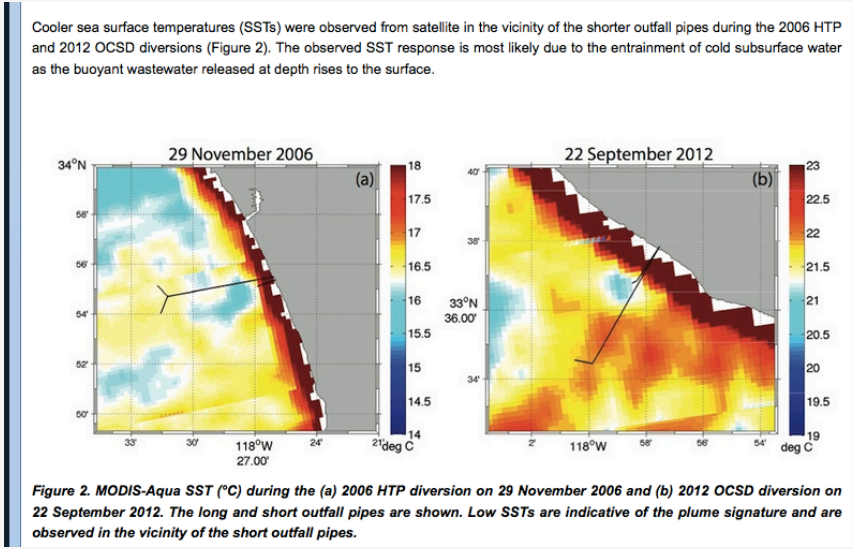
End User: Denver Water

- This project helped determine excessive runoff and sedimentation due to extreme rain and flooding in Denver area, and provided a fine scale map detailing potential erosion mitigation sites

Learn more:
http://develop.larc.nasa.gov/2015/summer_term/ColoradoWaterResourcesII.html

Wastewater Plumes Monitoring

NASA Develop Project – http://develop.larc.nasa.gov



Sea Surface Temperature near the Outflow pipes in the Southern California Bay

End Users:

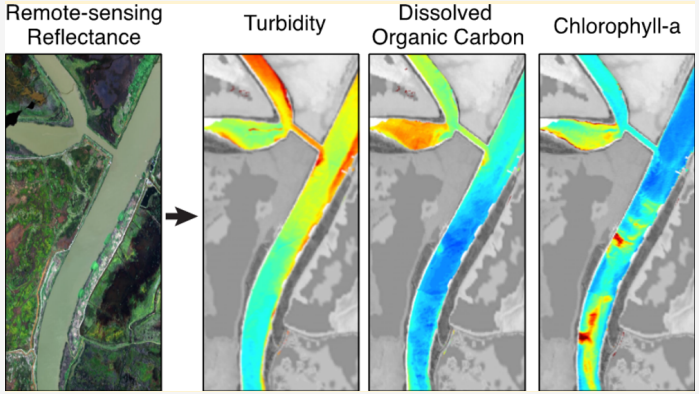
Hyperion Treatment Plant (HTP) and Orange County Sanitation District (OSCD), Southern California

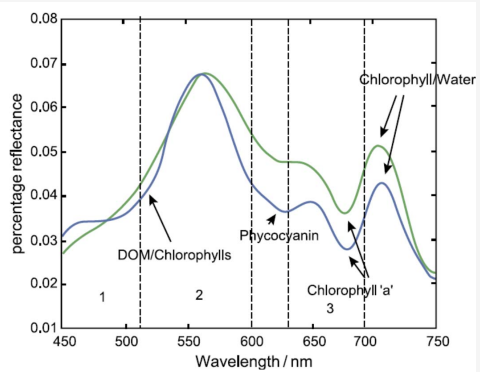
- Remote Sensing Measurements were used to detect wastewater plume and impact in the southern California Bight

Learn more: http://podaac-www.jpl.nasa.gov/OceanEvents/2014_10_22_WastewaterDiversions

Airborne Remote Sensing for Water Quality Monitoring

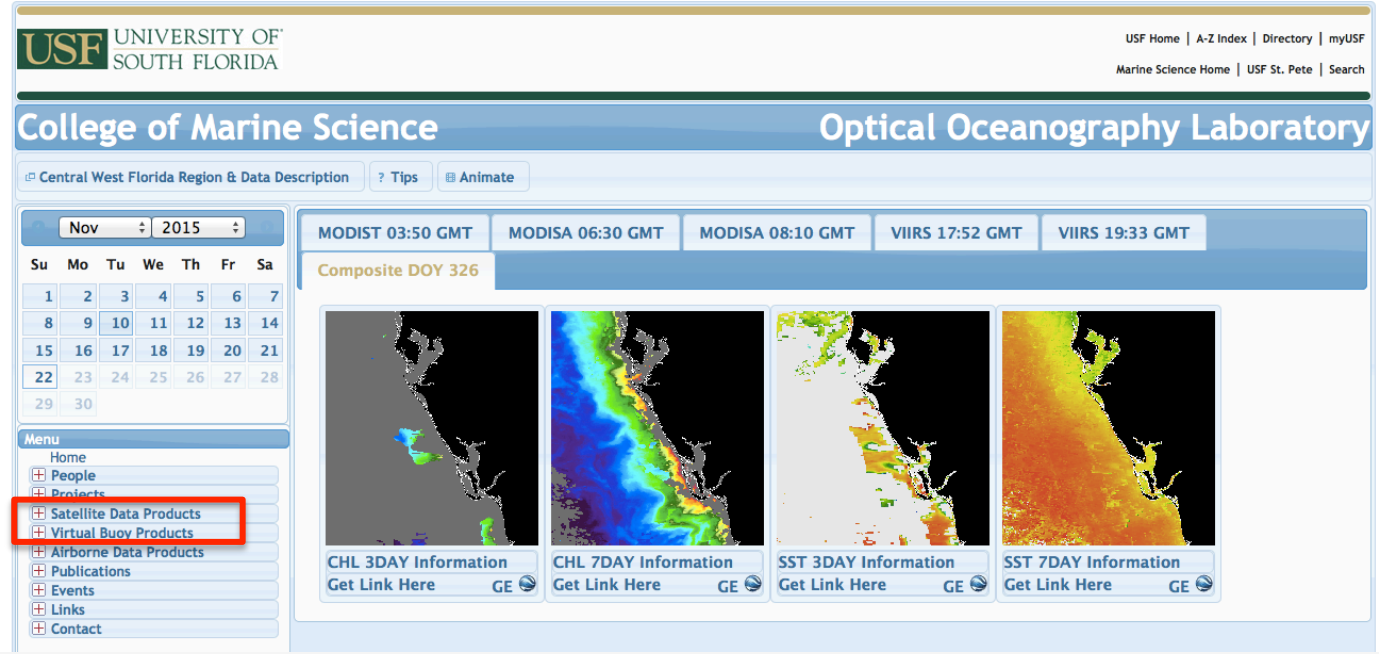
1. Water quality monitoring at high spatial resolution (2 m) in California Bay-Delta http://pubs.acs.org/doi/abs/10.1021/acs.est.5b03518
2. Monitoring of harmful algal bloom in Lake Erie (Summer of 2004) http://www.epa.gov/sites/production/files/2014-12/documents/habs-davis-12-10-14.pdf





Water Quality Monitoring using MODIS and VIIRS

In the Gulf of Mexico



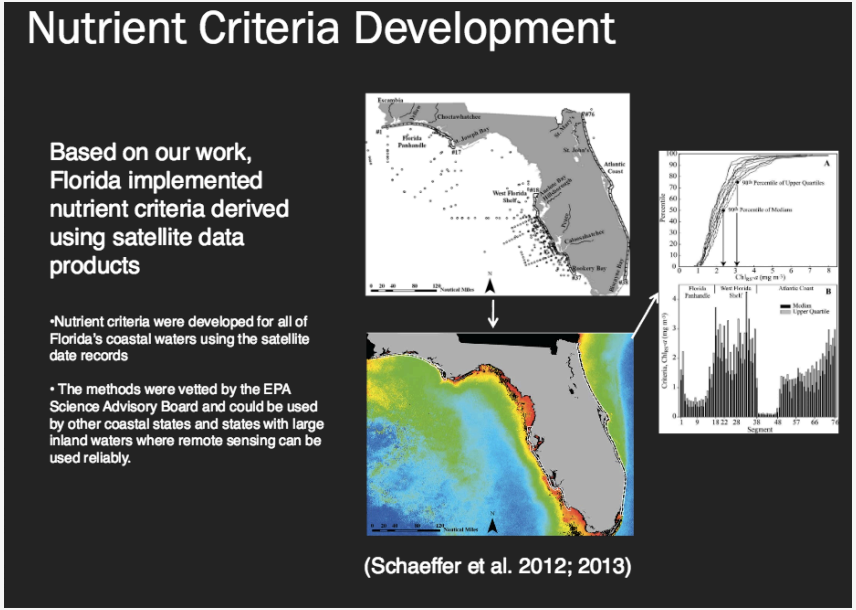
Learn more: http://optics.marine.usf.edu/cgi-bin/optics_data?roi=CWFL&current=1

Research to Application and Decision Support

NASA Applied Sciences Water Resources Program supports applied research for water quality monitoring and decision support activities, for example:

“Testing the Waters: Remote Sensing Applications to Water quality Management in Florida” -- Lehrter et al.

https://c3.nasa.gov/water/static/media/other/Lehrter_-_Water_Quality_Management_in_Florida.pdf



Thank You

The course material is available from
http://arset.gsfc.nasa.gov/

ARSET Listserv:
https://lists.nasa.gov/mailman/listinfo/arset